TESTING BIOASSESSMENT METRICS: MACROINVERTEBRATE, SCULPIN, AND SALMONID RESPONSES TO STREAM HABITAT, SEDIMENT, AND METALS

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Abstract. The purpose of this article is to report on the testing of responses of multimetric macroinvertebrate and habitat indices to common disturbances to streams: stream habitat alteration, excessive sediment, and elevated metals concentrations. Seven macroinvertebrate community metrics were combined into a macroinvertebrate biotic index (MBI), and 11 channel morphology, riparian, and substrate features were combined into a habitat index. Indices were evaluated by comparing the habitat results to fish population surveys and comparing the macroinvertebrate results to habitat ratings, percent fine sediments measured by Wolman pebble counts, and copper concentrations. Macroinvertebrate scores decreased with increasing percentages of fine sediments measured either across the bankfull or instream channel widths. Macroinvertebrate scores decreased with increasing copper. One metric, richness of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, was more responsive to both copper and sediment than was the multimetric MBI. Habitat scores corresponded well with the age class structure of salmonids, but not with that of benthic sculpins. Both salmonid and sculpin age classes declined with increasing percentages of fine sediments. The decline was graded with the sculpin age classes, whether fine sediments were measured across the instream or bankfull channel, whereas salmonids consistently responded only to the instream fine sediments.

Keywords: benthic macroinvertebrates, bioassessment, biological monitoring, copper, Idaho, multimetric index, pebble counts, salmonids, sculpins, sediment, stream habitat, water quality

1. Introduction

The use of biological surveys to regulate water quality has become widespread in the U.S.A. following the 1987 amendments to the federal Clean Water Act, where section 101(a) states that its primary objectives are to 'restore and maintain the chemical, physical, and biological integrity of the nation's waters'. To help develop state biosurvey programs, the U.S. Environmental Protection Agency (EPA) prepared a methods compendium of 'Rapid Bioassessment Protocols' for use in streams and rivers (Plafkin *et al.*, 1989). The 'RBPs' included protocols for stream physical habitat assessment and the collection and analysis of benthic macroinvertebrate and fish community data. The data analysis methods were influenced by Karr's example of using an aggregate 'index of biotic integrity' (IBI) for fish communities which is composed of several community variables, or metrics (Karr, 1981). In this approach, which the RBPs expand to macroinvertebrate communit-

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ies, the component metrics are expected to reflect important ecological principles, and to respond to the effects of pollutants or other stressors. Numeric values for the preferred biological condition of each metric are summed to an aggregate multimetric index. These protocols have subsequently been modified to reflect regional conditions and have been expanded and updated (Hayslip, 1993; Barbour *et al.*, 1999).

Water quality surveys in Idaho followed this national approach. By the early 1990s, the state water quality authority had developed regional monitoring protocols for biosurveys and begun applying the results to environmental regulation. Pilot studies to describe reference conditions and to select biological metrics for regional conditions were undertaken (Chandler *et al.*, 1993; Clark and Maret, 1993; Robinson and Minshall, 1995, 1998). However, in the mid 1990s, a series of federal court rulings addressed Idaho's classifications of streams to protect aquatic life uses, listings of impaired waters, and restoration plans (*Idaho Sportsmen's Coalition vs. Browner*, 1994, 1997a, b). The pace of biological monitoring and assessment in Idaho was abruptly accelerated in response to these rulings. In 1994, the court ruled that EPA had erred in approving Idaho's 1992 list of 36 water quality limited streams and ordered the EPA to prepare a more inclusive list within 90 days. In response, the EPA compiled existing lists of waters of concern and expanded the list to 962 waters that were potentially impaired. Most of the streams had no monitoring data available whatsoever (EPA, 1994). Except for waters that were shown to meet aquatic life goals, the court also ruled that all 962 waters must have cleanup plans completed within 8 yr. At the time, 'impaired' waters were not explicitly defined. Subsequently EPA has defined a water body as being biologically impaired if the attributes of one or more major biological groups (assemblages) has been modified significantly beyond the natural range of the reference condition (EPA, 1995a). The reference condition may be determined through sampling least-disturbed sites on similar types of waters, historical records, or expert opinion (Hughes, 1995). Approximately 2000 other stream segments have been identified that need to have their aquatic life conditions surveyed, uses designated, and if needed, added to the cleanup schedule. By 1999, 44 states had recent involvement in litigation related to developing lists of impaired waters or restoration plans for them (http://www.epa.gov/OWOW/tmdl).

One consequence of the court's orders in Idaho was to create a pressing need for biosurvey information from a large number of streams, located over a wide geographic area. In response to this need, a large set of matched habitat and invertebrate data were collected over wide gradients of human influences in Idaho, from sites located in wilderness to intensively cultivated or otherwise altered watersheds (Figure 1). The court's schedule did not allow time for extended data analysis or development of assessment tools. Because of this, simple additive multimetric macroinvertebrate and habitat indices were used as provisional tools to help interpret the large data sets that were being generated (IDEQ, 1996). The purpose of this

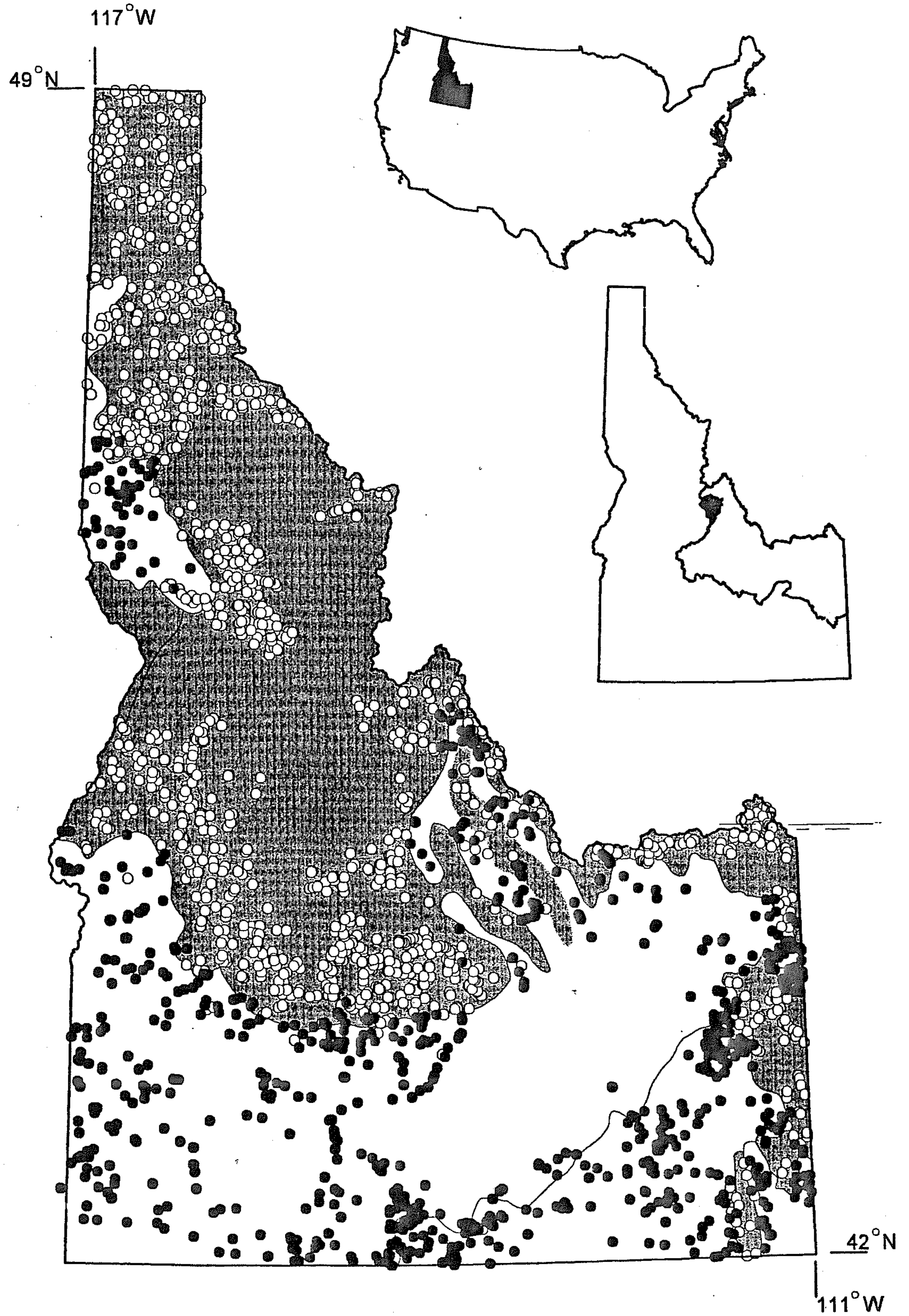


Figure 1. Locations of the 1874 stream sites sampled from 1994–1996 in the state-wide survey. Open dots show sample sites located in the montane ecoregions (gray shaped areas), solid dots show samples located in the semiarid ecoregions (unshaded areas). Inset maps show the Idaho study area and the locations of the fish and sediment (outline) and copper effects (shaded) portions of the study.

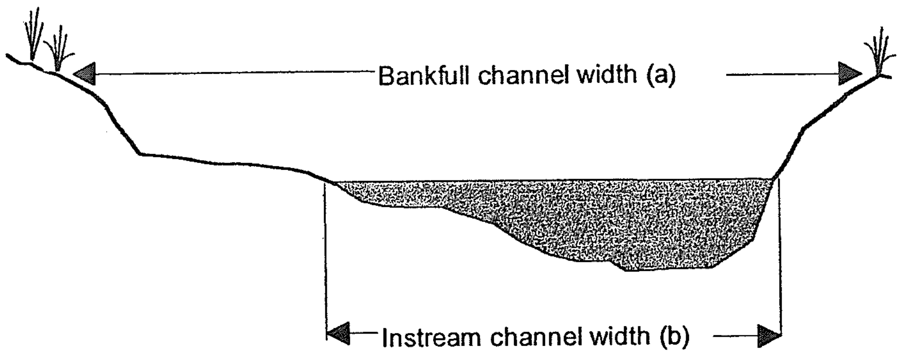
article is to report on testing the responses of these indices to common disturbances: stream habitat alteration, excessive sediment, and elevated metals concentrations.

The physical habitat structure of stream corridors is a major determinant of the potential aquatic communities. Stream energy sources and refugia can be disrupted by a variety of human disturbances. Urbanization, agriculture, or logging may result in channel straightening, loss of pools, loss of instream cover from large woody debris, and loss of leaf litter and shade from overhanging riparian vegetation, changes in flow regimes, and changes in substrate composition (Karr, 1995). These habitat features have been established to be important for salmonid fishes (Platts *et al.*, 1983; Bjornn and Reiser, 1991). While the RBP monitoring protocols describe these types of habitat measurements as being important to the overall stream health, little testing of overall RBP habitat ratings and macroinvertebrate relationships has been published. A report by Lammert and Allan (1999) on fish, macroinvertebrate, and habitat relationships in warmwater (non-salmonid bearing) agricultural streams in southern Michigan, U.S.A., is a recent exception.

Elevated trace metals concentrations can have significant local effects on aquatic ecosystems. While trace metals are naturally occurring and several are essential micronutrients, they may be toxic to aquatic life at higher concentrations. Elevated concentrations can result from mining activities due to leaching of mine wastes or the accelerated weathering of mineralized rocks as they are broken up and exposed to oxygen and precipitation (Runnels *et al.*, 1992).

Excessive sedimentation is a significant cause of water quality impairment in North America. In the United States, 34% and in Idaho, 93% of waters listed as impaired are attributed to excessive sedimentation (EPA, 1994, 1995b). The particle size of deposited stream bed sediments affects the flow resistance in the channel, the stability of the bed, and the amount of available aquatic habitat types. These in turn have significant effects on macroinvertebrate and fish communities (Minshall, 1984; Waters, 1995).

Thus the substrate is a fundamental part of the stream environment, and siltation is a ubiquitous concern. However, there is no consensus method for characterizing sediment in streams for biological surveys. Over 10 methods for evaluating sediment in streams are in use in North America, ranging in complexity from visual estimates to liquid nitrogen freeze cores (McDonald *et al.*, 1991). Our program uses Wolman pebble counts to characterize substrate particle sizes. Pebble counts of stream channel transects were developed as a method of characterizing the particle size distribution of the stream bed in order to calculate stream hydrology features: flow resistance, channel capacity, and streambed stability (Wolman, 1954; Kondolf, 1997). Recently, pebble counts have been recommended as an efficient, and repeatable means for evaluating the suitability of stream substrates for aquatic life (Fitzpatrick *et al.*, 1998; Conquest *et al.*, 1994; Bauer and Burton, 1993; McDonald *et al.*, 1991). To my knowledge, no evaluation has been published on the use of Wolman's hydrological procedure to evaluate the biological effects of excess fine sediments. Further, because pebble count techniques were developed to evaluate



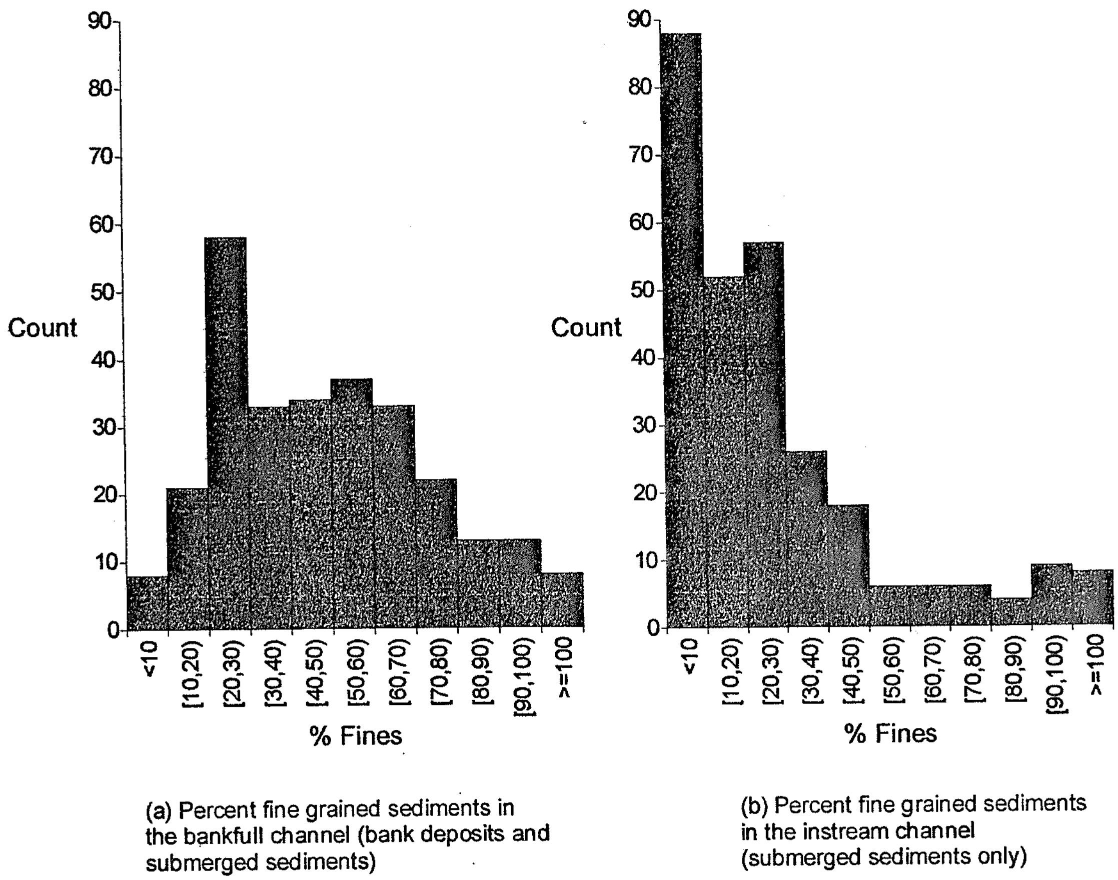


Figure 2. Percent fine-grained (<6 mm) surface deposits measured across transects of (a) the bankfull (bank deposits and instream sediments) channels and (b) instream channels.

channel capacities when the channel is full to overflowing (i.e. bankfull), and because they are necessarily done during low flow conditions, pebble counts record the distribution of particle sizes across the bankfull channel which include both submerged sediments and dry bank deposits (Wolman, 1954; Bauer and Burton, 1993). Depending on the channel shape, this means that much of substrate being evaluated for aquatic habitat suitability, is not even an aquatic habitat at the time of sampling. Since IDEQ's interests focus on suitability of habitats for aquatic life, the protocol was modified to focus on the aquatic portion of the stream channels. This article, compares the two methods through comparisons of macroinvertebrate and fish community metrics to percentages of fine sediment in both the bankfull (instream and bank deposits) and the instream portion of the channel only.

2. Methods

2.1. Physical Habitat Measures

Habitats were evaluated through a combination of qualitative and quantitative procedures derived from Hayslip (1993) and Bauer and Burton (1993), respectively. The qualitative habitat assessment factors were rated by comparing stream conditions to explicit condition descriptions from Hayslip (1993). Channel substrate size distribution in riffle habitats was measured by pebble counts at three riffles, with a minimum of 50 counts at set intervals per riffle. Prior to 1997, pebble counts were made across the bankfull transect of the stream channel, part of which is out of the water on the stream banks. Beginning in 1997, the pebble count protocol was modified to record the submerged substrate composition in addition to the overall bankfull channel substrate composition (Figure 2). Longitudinal habitat types were classified as pool, glide, run, or riffle. Mean width and depth was calculated by measuring wetted and bankfull conditions at three riffles, recording cross-sectional depth at a minimum of ten locations. Shading was measured with a densiometer at three riffle habitat units, calculations were weighted by habitat types and lengths. Stability and vegetative protection of the lower stream banks were measured longitudinally. Pool length, substrate, overhead cover, submerged cover, bank cover, maximum pool depth and width, and depth at pool tailout were measured. All of these variables were later totaled to calculate an overall habitat index (HI) score (Table I).

2.2. Macroinvertebrate and Fish Sampling

Macroinvertebrate samples were collected from a random point along three separate transects of riffle habitat units using a 0.1 m^2 Hess sampler with a 500 μm mesh. The samples were preserved separately and then composited in the laboratory. Following the initial removal of large and rare taxa, a minimum of 500 individuals were systematically hand picked from the composited sample, counted, and identified. Ephemeroptera, Plecoptera, and Trichoptera were usually identified to species, other insects (except Chironomidae) were identified to genus. Molluscs, copepods, and most other invertebrates were identified to order. Taxonomic identifications were made by contract laboratories.

Relative abundance and composition of fish communities were determined by one-pass electrofishing of 160 sample reaches in the upper Snake River and upper

TABLE I

Summary of habitat parameters, rationale, and values used in the Habitat Index (HI). Scoring ranges are shown in parentheses. Intermediate values are graded evenly between the ranges except for canopy cover and sinuosity

Habitat parameter	Rating points	
	Optimal	Poor
High gradient stream habitat (riffle/run prevalence)		
1. *Channel substrate*[a] – Percentage of surface sediments <6.3 mm diameter measured by pebble count transects	<2% (20)	100% (0)
2. *Instream fish cover*[b] – Estimate of extent of stable, refuge providing features	>50% (20)	<10% (0)
3. *Embeddedness*[b] – Degree that rubble and cobbles are surrounded by fine sediment (<6.3 mm diameter)	<25% (20)	(0) (0)
4. *Longitudinal habitat distribution*[a] – Balance and complexity of habitats	Balance of pool, glide, riffle, and run occurrences (20)	Homogenous (0)
5. *Channel shape*[b] – Prevalence of undercut banks or overhanging vegetation (i.e., 'Trapezoidal')	'Trapezoidal' (15)	Wide, flattened banks (0)
6. *Slow/fast water habitat ratio*[a] – Greater variety of velocities and depth provide better habitat	>0.93 (15)	0 (0)
7. *Wetted width/depth ratio*[a] – Wide, shallow streams provide little habitat and warm excessively	<2 (15)	>40 (0)
8. *Bank vegetative protection*[a] – Degree that rooting protects banks	>95% (10)	<30% (0)
9. *Lower bank stability*[a] – Extent of detached, sloughing, or cracking soil	>95% (10)	<30% (0)
10. *Streambank disruptive influences* – Amount of disrupted/removed vegetation	Not evident (10)	>70% bare soil or closely cropped vegetation (0)
11. *Riparian zone of influence*[b] – Estimate of the width of area that influences stream and extent of human removal of vegetation	Undisturbed width >4× stream width (10)	Little riparian vegetation (0)
	165 = total possible score	

TABLE I

(continued)

Habitat parameter	Rating points			
	Optimal			Poor
Low gradient stream habitat (glide/pool prevalence)				
1. *Pool substrate*[b] – Provides refuge for fish	Gravels, firm sands, submerged vegetation (20)			Hard-pan or bedrock (0) (0)
2. *Instream fish cover*[b]	Same as high gradient			
3. *Pool complexity*[a] – More diverse types of pools preferred	Mix of deep, large, and shallow pools (20)			Pools small and shallow or absent (0)
4. *Canopy cover*[a] – Mixture of conditions full sunlight and variably filtered sunlight preferred to full shading or lack of canopy	75% (20)	25% (11)	100% (6)	0% (0)
5. *Channel shape*[b]	Same as high gradient			
6. *Channel sinuosity* – Related to energy dissipation, benthos susceptibility to scour, and fish refugia	High (14)	Braided (6)		Low (2)
7. *Wetted width/depth ratio*[a]	Same as high gradient			
8. *Bank vegetative protection*[a]	Same as high gradient			
9. *Lower bank stability*[a]	Same as high gradient			
10. *Streambank disruptive influences*	Same as high gradient			
11. *Riparian zone of influence*[b]	Same as high gradient			
	165 = total best possible score			

[a] Quantitative (measured) parameter; [b] Qualitative (visually rated) parameter.
The parameter descriptions and scoring criteria listed here were reduced from several field sheets and a field booklet which provided a series of worksheets for crews to record their measurements and calculations for quantitative parameters. These may be obtained from the author. Additionally, they are similar to those published on the Internet and as a report by the U.S. Environmental Protection Agency in Barbour *et al.* (1999).

Salmon River basins in eastern and central Idaho. Single upstream pass electrofishing has been shown to be an adequate means for assessing species richness, abundance, and assemblage structure in small streams (Simonson and Lyons, 1995). Fish were tentatively identified using field guides, and measured. Unknown specimens and at least one specimen from each field identified species was vouchered and definitively identified by a qualified taxonomist.

2.3. Chemical and Macroinvertebrate Comparisons

No chemical data were routinely collected in the state-wide survey described above. However, the Panther Creek watershed in central Idaho has had extensive characterization of chemical conditions from 1992 to 1995 as part of natural resource damage assessment and site restoration studies of discharges from a hard rock mine. This forested, lightly roaded, watershed has few significant anthropogenic disturbances other than acid mine drainage containing elevated copper and cobalt concentrations (Mebane, 1994; Beltman *et al.*, 1999). With few confounding variables, it is possible to compare the responses of macroinvertebrate metrics to matched chemical concentrations. The water chemistry data were compared to matched macroinvertebrate samples at 31 locations collected both by Idaho's program and by Salmon National Forest personnel. Since both sampling efforts used 0.1 m^2 Hess samplers with 500 μm mesh, collected three replicates from riffle habitats during stable flow regimes, and used similar taxonomic effort, the data from both collections should be comparable.

Chemical data included in this analysis were restricted to those sample results that were filtered using a 0.45 μm filter, and analyzed by comparable laboratory methods.

2.4. Site Selection

Streams were sampled for three reasons: (1) streams that had been previously designated as being 'impaired'; (2) streams that may represent least-disturbed reference conditions and (3) other streams with little data on their conditions. Once the stream was selected for sampling, sites were selected to sample different conditions occurring along the stream's course, such as changes in ecoregions as streams pass from montane to valley areas, valley types, stream order, or land uses. Each sample site consisted of a reach 20 times the mean stream width or 100 m long, whichever was greater. Samples were collected from June through September each year, with crews starting with the lower elevation streams and working toward the higher elevations as runoff ended and flows stabilized.

Depending on the year, samples were collected by 6 to 12 field crews consisting of 3 persons each, based in different regions of the state. Prior to the field seasons, the regional crew leaders trained together to standardize data collection. The educational requirements for the crew leaders included undergraduate or higher training in aquatic biology. Many of the crew members had completed or were enrolled in natural science programs, however a science education was not mandatory. Rather, evidence of a favorable work ethic, maturity, and of their abilities to understand and explicitly follow protocols were emphasized. During the field season, audits were made by a central state team to keep consistency among the teams.

2.5. Index calculations

This study evaluates previously devised habitat and macroinvertebrate indices that have been used by Idaho DEQ to assess stream conditions (IDEQ, 1996). The physical habitat index is calculated by measuring or visually inspecting eleven stream habitat attributes. These attributes were assigned scores from a continuum of conditions that were assumed to range from optimal to poor for aquatic fauna (Table I).

The macroinvertebrate biotic index (MBI) is calculated by combining seven metrics of community structure, community balance, and functional feeding groups. Each metric is normalized to a unitless value from 0 to 1.0, where 0 is the minimum possible value and 1.0 is the maximum value that was recorded for that ecoregion during 1993–1995 (Table II). If metric values from 1996 or 1997 sites exceeded the earlier ecoregional maxima, they were given a value of 1.0. Thus a MBI score has a possible value of 0 to 7.

2.6. Data analysis

Only the index scores were available for analysis for the entire statewide data set. Raw data were available only for the region of eastern Idaho. Thus, the number of sites in different analyses varies depending on what data were available. The evaluation of the habitat and macroinvertebrate indices consisted of five comparisons:

1. *A priori groups of reference and test streams.*
   Regional IDEQ biologists were asked to assign streams that they were familiar with into a priori categories of least-disturbed reference sites or apparently impacted test sites. The sites were categorized following Hughes' (1995) recommendations for field reconnaissance of potential reference sites (Table III). Sites classified as impacted had clear departures from at least one factor. Macroinvertebrate data were not considered in their selections.
2. *Grouping sites by high or low habitat index scores.*
   All sites sampled in the state-wide program from 1994–1996 were grouped by ecoregion and rank ordered by habitat index scores. The invertebrate scores from sites with habitat index scores ranked above the upper quartile (highest 25th percentile habitat index scores) and ranked below the lower quartile (lowest 25th percentile habitat index scores) were compared.
3. *Fish population metrics.*
   All sites sampled in the state-wide program from I compared the fish sampling All sites sampled in the state-wide program from results to the corresponding site habitat index and sediment characteristics. Age classes were assigned to salmonid species based on unpublished regional Idaho Department of Fish and Game length at age reports. Age classes were assigned to sculpin (*Cottus*) species using Wydoski's and Whitney's (1979) review of length at age relationships.

TABLE II

Metrics included in the MBI, their expected response to impaired water quality, and ecoregional maximum values. The highest metric value recorded from a ecoregion was assigned as value of one. Values from each sample were normalized from zero to one as a proportion of the ecoregional maximum values

Ecoregion	Ecoregional grouping	HBI	Number of EPT taxa	% EPT	Total number of taxa	% Scrapers	% Dominance (single taxa)	H′
Expected response		↑	↓	↓	↓	↓	↑	↓
Blue Mountains	Montane	8.1	36	85	52	55	88	1.32
Middle Rockies	Montane	8.6	26	92	45	76	87	1.20
Northern Rockies	Montane	9.5	38	94	53	85	88	1.34
Columbia Basin	Semiarid	7.4	28	73	47	52	86	1.34
Northern Basin and Range	Semiarid	8.8	35	92	53	78	85	1.26
Snake River Basin/High Desert	Semiarid	8.0	34	100	42	78	84	1.29

HBI – Hilsenhoff biotic index modified with regional tolerance values to sediment and organic pollution (Hilsenhoff, 1987; Clark and Maret, 1993). EPT taxa – Number of taxa in the Ephemeroptera, Plecoptera, and Trichoptera orders; these taxa are generally pollution sensitive. % Scrapers – Percentage of herbivores which feed by grazing on hard surfaces. A decrease in scrapers is assumed to reflect a decrease in diatoms which could be associated with increased sedimentation or organic pollution. % Dominance – percentage of the community by the single most abundant taxon; expected to increase with increased environmental stress. H′ – Shannon's diversity index. Index of richness and evenness, calculated using Log_{10}. Undisturbed environments expected to have high species richness with no species dominating the assemblage.

TABLE III

Variables used for classifying a priori reference and test sites

Variable	Criteria
Roads	Not constraining riparian zone, crossings are infrequent, no evidence of road associated failures from culverts or gullies to streams.
Riparian vegetation extensive and old	Riparian growth is considered extensive when it occurs all along the shoreline and is capable of shading the stream and buffering human influences. It is considered old when overhangs the stream or deposits large woody debris
Riparian structure complex	Complexity characterized by presence of a canopy, understory and groundcover (trees, shrubs, and groundcover
Channel complex	Mixture of pool, glide, riffle, and run habitat types
Habitat structure complex	Substrate heterogeneous
Chemical stressors likely minimal	Likely sources of chemical stress are few (e.g. unbuffered croplands, irrigation returns, active or in-active mining areas, regulated discharges), or if potential sources present, chemical data shows standards or guidelines met, and thus effects are unlikely.
Shoreline/channel modification minimal	Evidence of riprap, channel straightening, vegetation removal or other disturbances absent or minimal.
Flow modifications minimal	Upstream impoundments absent. Irrigation withdrawal or other diversions absent, or if present, likely cause minimal disruption to the hydrologic cycle (i.e. acknowledging that almost all streams located in the semi-arid basin/lowland ecoregions will have some water withdrawals)
Evidence of excessive sedimentation absent	Apparent anthropogenic sediment increases not noted (e.g. crop or road gullies, livestock bank trampling, mass wasting). No field notes of highly turbid conditions. No indications from habitat variables of excessive sedimentation (e.g. No 'poor' qualitative cobble embeddedness estimates ($\geq$75%), channel substrate <50% fine sediments (measured as bankfull).
Grazing in riparian zone minimal	Absence of laid back, trampled, or unstable banks.
Logging, construction, or other disturbances minimal	If present, buffered from riparian zone
Agricultural disturbances	Croplands not impinging riparian zone, runoff or irrigation returns minimal

Modified from Hughes (1995).

4. *Macroinvertebrate metrics and fine sediments.*
   The macroinvertebrate metrics were compared with the percentage of the stream channel widths composed of fine sediments (particles <6 mm). Data are from 279 sites sampled in 1997 in eastern and central Idaho. Metrics were compared to sediments measured both across the bankfull channel section that includes both bank deposits and submerged sediments, and to submerged sediments only.
5. *Macroinvertebrate metrics and copper concentrations.*
   Copper concentrations were compared to the MBI and to other metrics that have been reported in the literature to be responsive to elevated concentrations of copper or other metals. When differences between groups are reported, the statistical significance of differences was tested by ANOVA followed by Tukey's 'honest significant difference' multiple comparison procedure (Zar, 1984).

3. Results

3.1. Invertebrate Index Scores and Habitat Condition

A large set of matched habitat and invertebrate data were obtained across Idaho (Figure 1). Regional IDEQ biologists identified a priori 296 least-impacted reference and impacted sites in eight ecoregions. 257 of these were located in the four ecoregions that cover about 90% of Idaho: the montane, relatively moist Northern Rockies and Middle Rockies ecoregions, and the relatively lower, arid Snake River Basin/High Desert and Northern Basin and Range ecoregions. The other smaller and disjunct ecoregions had too few sites to evaluate. Mean invertebrate and habitat scores from the reference sites were similar within the two montane and two lowland ecoregions (Figure 3a). Impacted sites had significantly lower invertebrate scores than reference sites. Invertebrate scores at reference sites in the lowland ecoregions tended to be lower than those from reference sites in montane regions were.

Using quantitative habitat rankings, sites ranked in the upper quartile had significantly higher invertebrate scores than those in the lower quartile (Figure 3b). In all cases, the groups of sites with the higher habitat scores had higher invertebrate scores than did groups of sites with lower habitat scores. The mean invertebrate scores were similar between the two montane ecoregions, and between the two semiarid basin/lowland ecoregions. Invertebrate scores were generally lower for the lowland ecoregions than the montane ecoregions. The pattern from these groupings was similar to the pattern resulting from the a priori groupings. Groupings based on ranking the quantitative habitat index were similar to the groupings by the regional biologists.

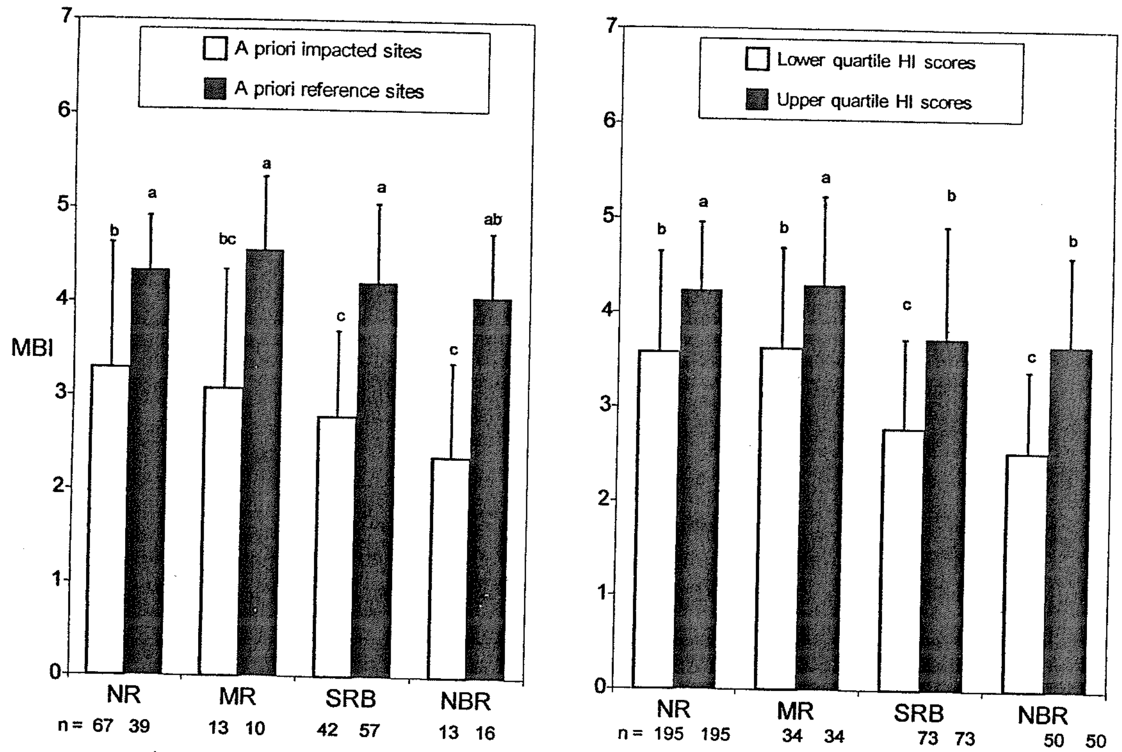


Figure 3. Mean macroinvertebrate biotic index (MBI) scores grouped within ecoregions by sites selected a priori as impacted or least-disturbed reference sites (left); and from sites rank ordered by habitat index (HI) scores and grouped into upper and lower quartiles (right). Error bars show standard deviation of the mean. Groups designated by different letters are significantly different at $P<0.05$ using ANOVA and Tukey's multiple comparison procedure. NR – Northern Rockies; MR – Middle Rockies; SRB – Snake River Basin/High Desert; NBR – Northern Basin and Range.

3.2. Fish, habitat, sediment, and invertebrate relationships

The number of fish species captured ranged from 0–7. Typically 2–3 species were captured at locations where fish were captured. The salmonid and sculpin families were widely distributed, occurring respectively at about 70 and 50% of the sites. Individual species were much less widely distributed. The introduced eastern brook trout occurred the most frequently at 31% of sites surveyed (Table IV). Because of the limited distribution of individual species, the comparisons of fish to habitat and sediment focus on the widely distributed salmonid and sculpin families. These families are considered generally intolerant of warm water, excessive sediment, or organic pollution (Hughes and Gammon, 1987).

The distribution of fine sediments sampled by transects of the bankfull channel which includes both submerged sediments and bank deposits located out of the water, and pebble counts of the instream portion only is shown in Figure 2. The bank deposits are only infrequently submerged during high flows that fill the bankfull channel (Figure 2 (top)). Percentages of fine sediments measured by bankfull pebble counts averaged 45%, with many streams having >50% fine sediments (Figure 2a). Percentages of fine sediments measured by instream pebble counts of

TABLE IV

Occurrence frequency of fish families and species at 160 stream segments in central and eastern Idaho

Family	Species	Origin	Occurrence frequency (%)	Occurrence rank (of 17)
Salmonidae			*69*	
Chinook salmon	*Oncorhynchus tshawytscha*	N	3	13
Cutthroat trout	*Oncorhynchus clarki*	N	26	2
Rainbow trout	*Oncorhynchus mykiss*	N-I[a]	17	6
Cutthroat-rainbow hybrid	*Oncorhynchus clarki X O. mykiss*		2	14
Bull trout	*Salvelinus confluentus*	N	3	11
Brook trout	*Salvelinus fontinalis*	I	31	1
Brown trout	*Salmo trutta*	I	2	14
Mountain whitefish	*Prosopium williamsoni*	N	1	16
Cottidae			*54*	
Mottled sculpin	*Cottus bairdi*	N	18	5
Paiute sculpin	*Cottus beldingi*	N	19	4
Shorthead sculpin	*Cottus confusus*	N	20	3
Cyprinidae			*19*	
Longnose dace	*Rhinichthys cataractae*	N	5	10
Speckled dace	*Rhinichthys osculus*	N	13	8
Redside shiner	*Richardsonius balteatus*	N	14	7
Utah chub	*Gila atraria*	N	1	17
Catostomidae			*12*	
Mountain sucker	*Catostomus platyrhynchus*	N	10	9
Utah sucker	*Catostomus ardens*	N	3	11
No fish present			*14*	

Species origin: N – Native, I – Introduced. I[a] Rainbow trout are native to some parts of Idaho but have been extensively introduced beyond their native range (Simpson and Wallace, 1982).

the same locations averaged 25%, with few streams having >50% fine sediments (Figure 2b).

Associations between percentages of fine sediments in bankfull and instream transects, the habitat index, and fish responses are shown in Figure 4. The data are grouped by the number of salmonid and sculpin age classes occurring in the

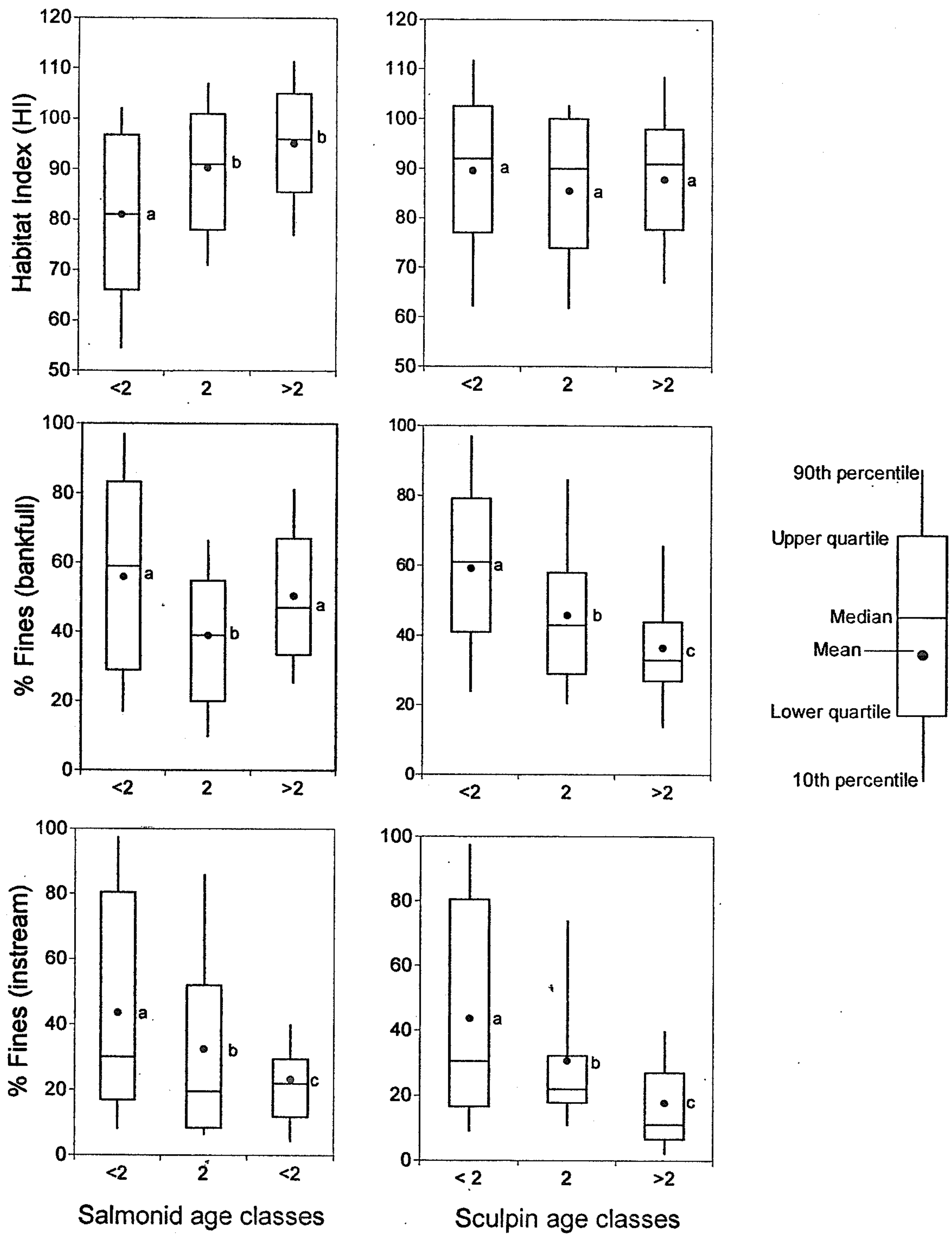


Figure 4. Salmonid and sculpin age classes occurring in 100 m reaches compared with habitat index ranges and percentages of channel widths covered with fine-grained (<6 mm) sediments. 'Bankfull' includes bed materials located both in the submerged channel and on the banks; 'instream' includes bed materials from the submerged portion of the channel only. Different letters show whether the means were significantly different at $P<0.05$ using ANOVA and Tukey's multiple comparison procedure.

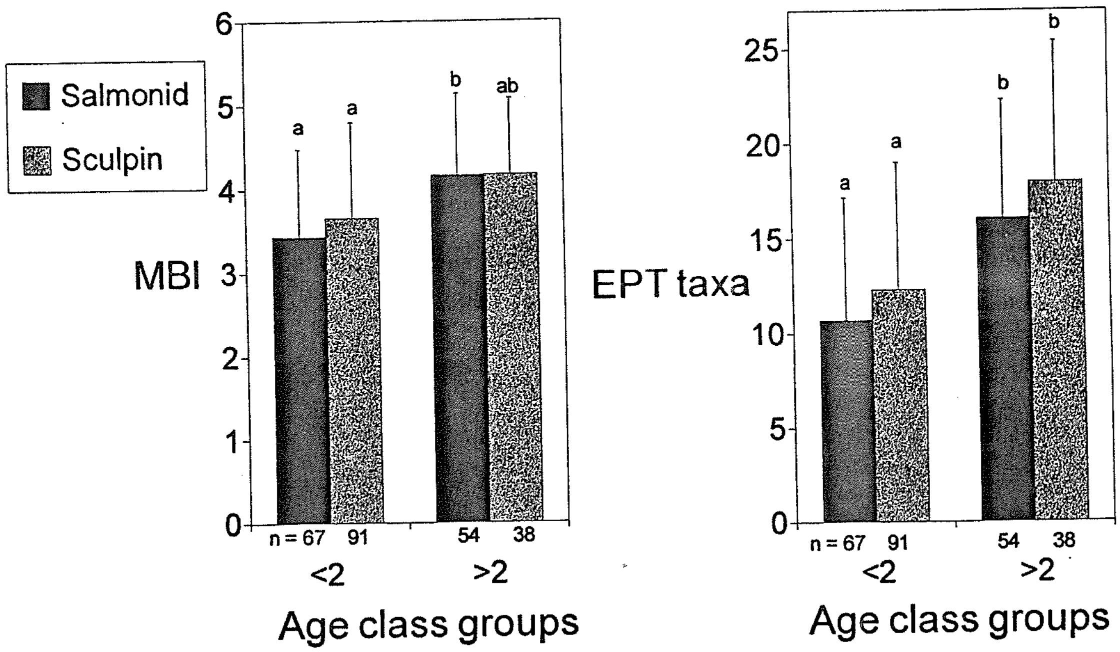


Figure 5. Relationships between macroinvertebrate and fish metrics. Mean MBI and EPT taxa richness values are grouped by age class occurrences of salmonids and sculpins. Error bars show one S.D. Means marked with different letters are statistically different at $P<0.05$ using ANOVA and Tukey's multiple comparison procedure.

study reaches. Age classes of a species of fish were assumed to be an indication of whether a self-sustaining population of that species is present at that location. I considered the absence of a species or the presence of only one age class to indicate that a reproducing population was not present at that location, two age classes were indeterminate, and three or more indicate a reproducing population.

When the instream, submerged portion of the channel was considered, sites with multiple age classes of salmonids were significantly more common at sites with less fine sediments. The associations between sculpin age classes and fine sediments were less variable than with the salmonids. For sculpin, multiple age classes were more common at sites with less fine sediments, measured as either bankfull or instream transects. Locations with multiple age classes of a salmonid species present tended to have higher and less variable habitat scores than did locations with two or fewer age classes present. There was no relationship between sculpin age classes and the overall habitat index. Locations where several age classes of salmonid or sculpin species were captured were associated with higher invertebrate scores than were locations where less than two age classes occurred (Figure 5).

3.3. Sediment and Invertebrate Relationships

All metrics were significantly correlated with the percentages of fine sediments regardless whether measured across the entire bankfull channel or the instream portion (Figures 6 and 7). In all cases, correlations were similar but slightly stronger

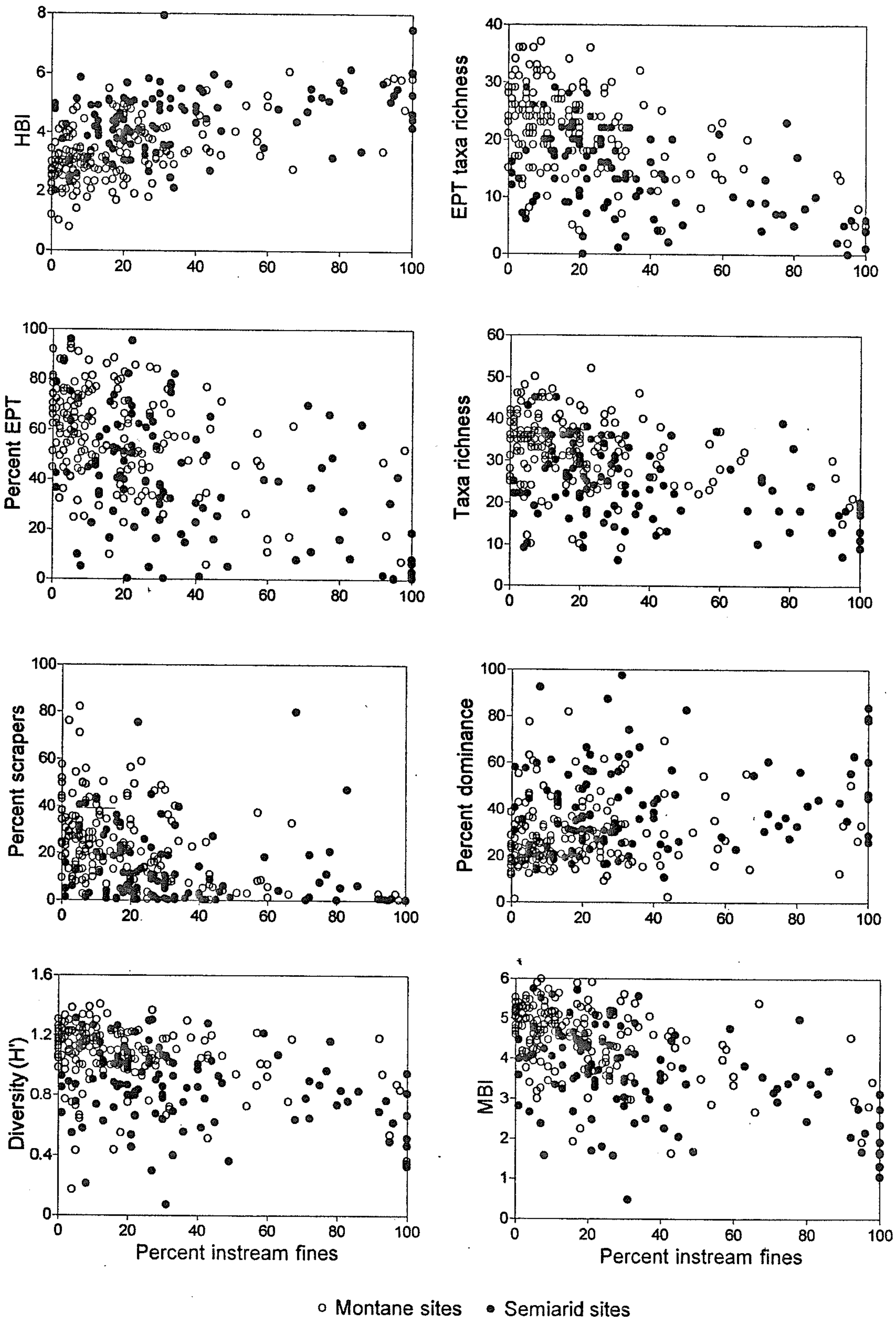


Figure 6. Relationships between macroinvertebrate biotic index (MBI) metrics and the percentage of the instream-channel covered with fine grained (<6 mm) surface sediments.

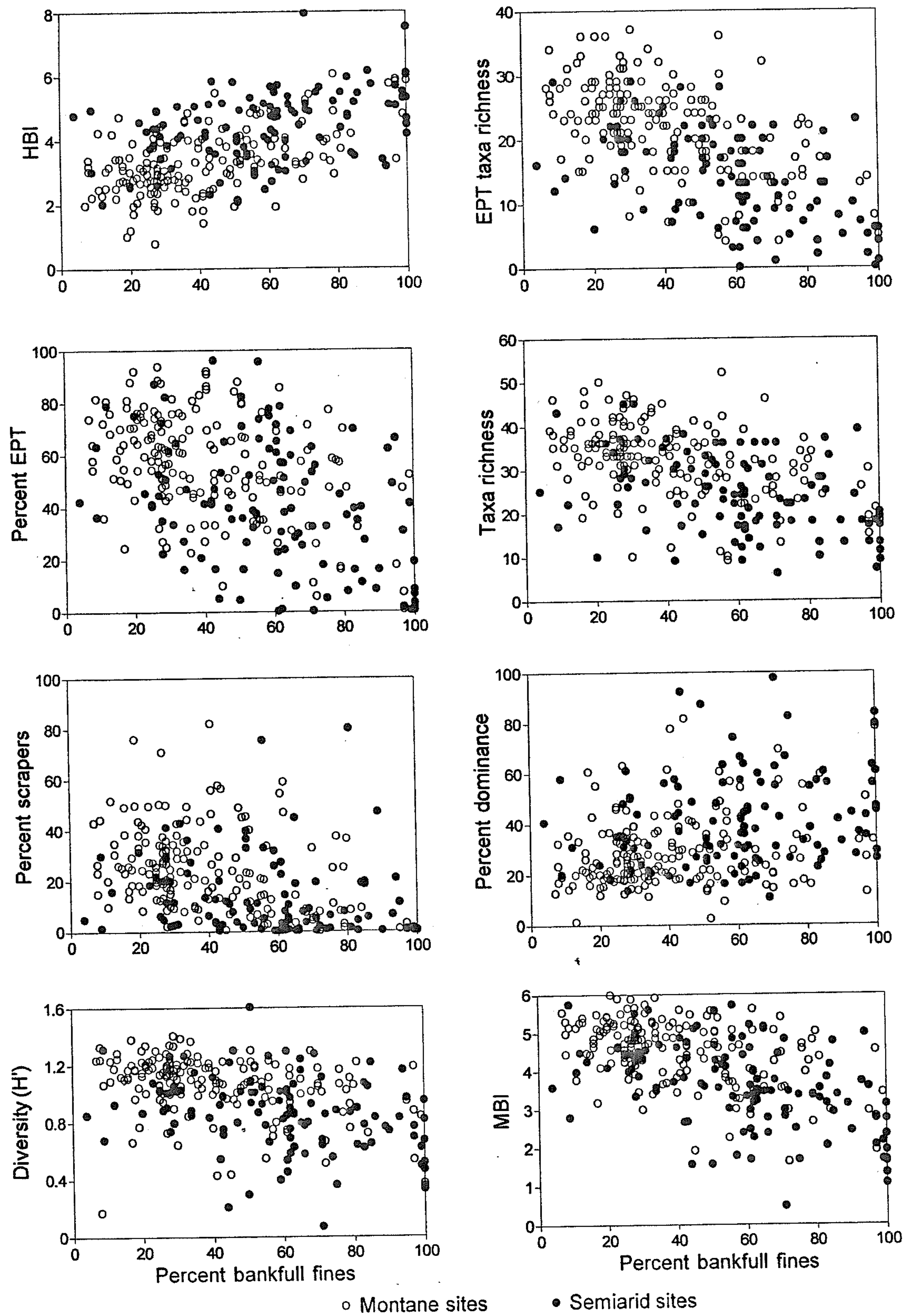


Figure 7. Relationships between macroinvertebrate biotic index (MBI) metrics and the percentage of the bankfull-channel width covered with fine grained (<6 mm) surface sediments and bank deposits.

between the macroinvertebrate metrics and the percentage fine sediments measured across the bankfull stream width (data not shown). The relationships of the bankfull fines and submerged fines and macroinvertebrate metrics are in most cases similar: bankfull plots appear to have simply been spread out and shifted to the right. High metric values (or low in the case of the HBI and dominance) occurred more commonly in the montane ecoregion groups than in the semiarid lowland ecoregions which are subject to more human disturbance. However, the patterns of responses of the metrics to particle size were similar regardless of ecoregion.

The percent scrapers functional feeding group metric appears to be an exception to this pattern. For most of the macroinvertebrate metrics and either bankfull or submerged fine sediments, the data form a cloud of points with linear, graded responses to increasing percentages of fine sediments. In contrast, the percent scrapers metric behaves with an apparent threshold of tolerance to increasing percentages of fine surface sediments. Above about 40% fine instream sediments, few scrapers are found (Figure 6). This pattern is less pronounced with bankfull fine sediments (Figure 7).

3.4. Copper and Macroinvertebrate Relationships

Relationships between copper concentrations, the MBI and other macroinvertebrate metrics are shown in Figure 8. All water samples collected from areas unaffected by mine discharges had low concentrations of metals. Water samples collected from affected areas had elevated concentrations of copper and cobalt. The results shown here focus on copper because of its much greater acute toxicity to fish than cobalt (Marr *et al.*, 1998). Mean copper concentrations from upstream Panther Creek and tributaries were very low (<0.5 to $2.5\ \mu g\ L^{-1}$); downstream of the mine drainage copper was one to two orders of magnitude higher (12 to $>1000\ \mu g\ L^{-1}$). Overall abundance did not respond consistently to low or intermediate copper concentrations, only falling off at comparatively high ($>40\ \mu g\ L^{-1}$) copper concentrations. Macroinvertebrate samples with high abundances collected from sites with copper elevated above the standard of about $6\ \mu g\ L^{-1}$ had low diversity, being dominated by chironomid midges and *Brachycentrus* caddisflies (data not shown). Ephemeropteran taxa richness and abundance were the most robust metrics for copper contamination, with no overlap between values with elevated and non-elevated copper concentrations. Combining ephemeropteran, plecopteran, and trichopteran (EPT) taxa into one richness or abundance metric also discriminated among the high-low copper locations well. The multimetric invertebrate index was less responsive, although it still showed a strong response.

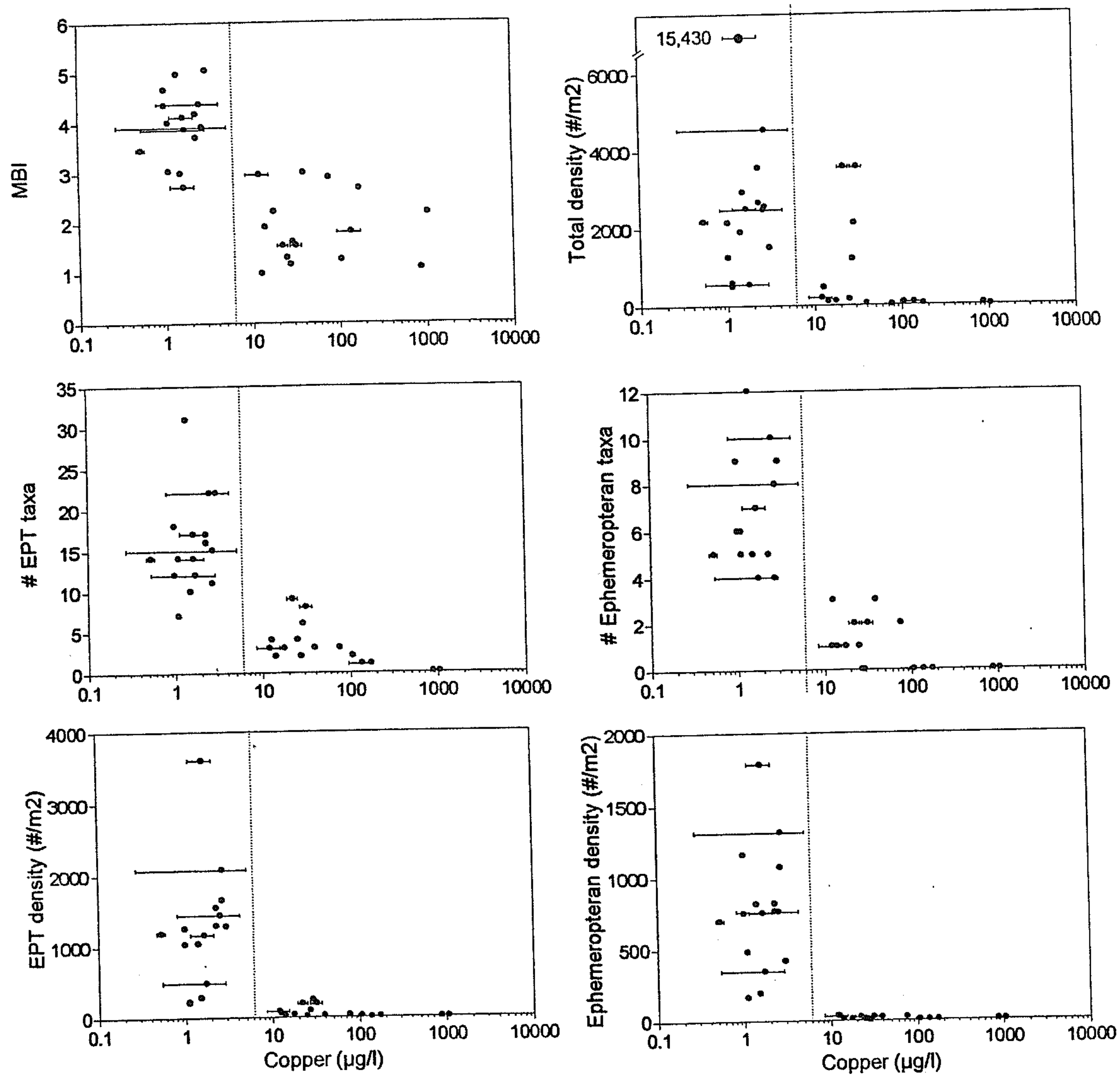


Figure 8. Relationships between dissolved copper concentrations (45 μm filtered) and macroinvertebrate metrics in the Panther Creek, Idaho watershed. Vertical dashed line shows approximate acute copper water quality criteria ($\approx 6\ \mu g\ L^{-1}$). Mean copper concentrations are shown for those locations which were not sampled for metals at the same time as the macroinvertebrate collections. These locations are indicated by values with error bars. Error bars show +/- one standard deviation of the mean.

4. Discussion

4.1. Macroinvertebrate Response

Macroinvertebrates showed a clear and measurable response to human disturbance measured in three ways:

(1) Measured as changes in the physical habitat conditions at the site. Sites that had relatively good habitat attributes tended to have higher invertebrate scores.

(2) Measured as sedimentation from land uses such as agriculture and grazing. The invertebrate metrics were inversely correlated with increasing amounts of fine sediments.

(3) Measured as effluent from mine drainage. Sites with copper concentrations exceeding water quality standards had lower invertebrate scores than did reference sites.

Further, these evaluations provide insight into limitations and means to improve the approach.

4.1.1. *Sediment and Macroinvertebrate Metrics*

The MBI and all seven of its component metrics were correlated with percentages of fine surface sediments and with each other. Of the seven component metrics and the composite invertebrate index, EPT richness was most strongly correlated with increasing fine surface sediments. Each metric and the composite index performed adequately by giving a generally graded response to increasing percentages of fine surface sediments. However, strongly correlated metrics of similar community features may simply provide weighting rather than additional information to the overall index. Robinson and Minshall (1998) and Barbour *et al.* (1992, 1996) have reported on metric redundancy and discrimination, and conclude that highly redundant measures should be eliminated from multimetric indices in favor of metrics that provide new information. These results support these recommendations. For example, both Shannon's diversity and percent dominance metrics are based on the premise that in most undisturbed environments, no species should dominate the assemblage. Since they were strongly correlated, the two metrics merely weight the index rather than providing additional information. In her review of a large number of ecological diversity studies, Magurran (1988) reported that indices weighted towards species richness are more useful for detecting differences between sites than are indices that emphasize the dominance/evenness components of diversity. Percent EPT and EPT taxa richness both reflect the premise that these three orders consist of pollution intolerant organisms. Further work to refine the invertebrate index should examine both discriminatory power and redundancy of potential metrics in response to gradations in fine deposited stream sediments.

The response of percent scrapers to increasing percentages of instream surface sediments was intriguing when compared to other reports. The data suggest a threshold of about 40% fine sediments where the occurrence of scrapers drops markedly and at lower percentages, grazing and scraping macroinvertebrates are unaffected. In contrast, Tait *et al.* (1994) found that the composition of scrapers increased in response to increased primary production resulting from the loss of stream shading associated with livestock grazing. Thus, while the composition of scrapers appears to be a responsive metric for sedimentation, the results should be examined carefully since the direction of response may vary.

4.1.2. *Copper and Macroinvertebrate Metrics*

The MBI performed strongly, with sites collected from unaffected sites scoring from 2.7 to 5.1 with a mean of 4.0. MBI scores from sites with elevated copper concentrations ranged from 1.0 to 3.0 with a mean score of 1.9. The composite invertebrate responses were dampened compared to the individual mayfly metrics. Ephemeropteran richness and density have been shown to be sensitive and reliable indicators of adverse effects of dissolved copper and other metals in controlled experimental stream dosing studies (Winner *et al.*, 1980; Clements *et al.*, 1988; Kiffney and Clements, 1994) and in field studies (Beltman *et al.*, 1999; Clements and Kiffney, 1995). If metals are the specific stressor of concern, these metrics would be more relevant than a multimetric metric.

4.1.3. *Ecoregional Patterns*

A major purpose of organizing stream assessments by ecoregions is to understand spatial patterns of realistically attainable conditions of aquatic ecosystems (Omernik and Gallant, 1986). To refine this approach, more detailed sub-ecoregions are being delineated in the United States (Omernik, 1995). In contrast to this effort, the present results suggest that for a multimetric analysis of macroinvertebrate communities, ecoregions with similar features could be combined to define the reference condition. Invertebrate scores at least-disturbed potential reference sites from different ecoregions were similar within the basic montane and semiarid-lowland groups. In the semiarid, lowland ecoregions of Idaho, few streams in their natural, reference condition persist due to alteration for agriculture. Identifying least-disturbed locations among ecoregions with similar attributes may allow monitoring a larger number of reference sites which would provide better understanding of the attainable conditions than would limiting the selections to within delineated ecoregions or sub-regions. In contrast to the lowland ecoregions, numerous stream reaches in their natural conditions were identified in the montane ecoregions.

Conclusions from other studies vary. Robinson and Minshall (1998) conclude that different taxon groups and metrics discriminated between test and reference sites in adjacent semiarid ecoregions. However, Barbour *et al.* (1992) reported that macroinvertebrate data from reference sites in Oregon, Colorado and Kentucky could be classified into montane and valley groupings. Whittier *et al.* (1988) reported that macroinvertebrate communities in widely separated montane areas of Oregon and nearby areas were similar, whereas communities from non-montane areas were different from montane areas and from each other.

4.1.4. *Atypical Streams*

This multimetric approach was reliable only for 'typical' perennial streams, making up about 93% of the data. Samples collected from pristine, spring-fed streams near their source and from oligotrophic lake outlets received very low invertebrate scores. The macroinvertebrate communities in spring-fed streams and lake outlet streams have been reported to bear little resemblance to that found in nearby streams. Anderson and Anderson (1995) compared insect fauna of spring habitats to a nearby stream in central Oregon. Diptera comprised over 90% of the spring communities, with other orders were uncommon and low in species richness and abundance. Ephemeroptera and Plecoptera were nearly absent. Robinson and Minshall (1990) reported that oligotrophic lake outlets had low species richness and were dominated by collector-filterer Dipterans. This influence persisted for several hundred meters downstream of the outlet. The MBI and other published multimetric analyses are based on the model of 'typical' natural streams and are all heavily influenced by the Ephemeroptera, Plecoptera, and Trichoptera orders (e.g. Fore *et al.*, 1996; Barbour *et al.*, 1996; Kerans and Karr, 1994).

Severely disturbed streams with very low macroinvertebrate densities are another special case. The use of relative composition metrics has the potential to dampen the signal of the multimetric index. In a somewhat contrived example, one grazing mayfly with a low pollution tolerance rating would receive a score of 3.0 out 7.0 by receiving the highest possible scores for percent scrapers, the HBI, and percent EPT. While this is not a high score, it does not stand out from other intermediate scores. This dampening by the multimetric index impedes one purpose of a multimetric approach, to screen for anomalous waters that should be further evaluated. This is further illustrated in Figure 8 where the plot of total density versus copper shows the near extinction of even the most tolerant macroinvertebrates at high copper concentrations (top right). The corresponding invertebrate scores for these locations are generally lower than the reference sites, but often do not fully reflect the severity of the impacts. The taxa richness metrics provide a better defined and graded response to the copper contamination. At high concentrations the EPT orders disappear completely. However, the taxa richness metrics do not distinguish between when a few individuals in each taxa occur and when they are abundant. Only the density metrics show the full severity of the situation: the extinction of major taxonomic groups. Invertebrate drift from unaffected tributaries may account for the occurrence of a few highly intolerant individual organisms into highly polluted sections of streams (Beltman *et al.*, 1999). After recognizing this limitation, the use of the MBI has been restricted to samples with at least 100 organisms in a composited sample (333 m^{-2}) to avoid applying community structure metrics inappropriately.

4.2. Habitat and Fish Communities

Multimetric indices using fish communities have been developed for water quality assessment in several regions of North America including the Midwestern United States, Southern Ontario, and the Willamette River, Oregon (Karr, 1991; Steedman, 1988; Hughes and Gammon, 1987). These indices are derived from Karr's index of biotic integrity (IBI) which consists of 12 metrics of fish communities, including measures of abundance, trophic composition, species richness, species composition, and individual fish condition. However, this approach has not yet been broadly applied in coldwater, western streams. Least disturbed streams in the Upper Snake River basin of Idaho have few fish species, with some streams only having one species. Introduced salmonids are widespread, which tends to homogenize the fish assemblage in depauperate systems (Maret *et al.*, 1997). The most remote, pristine streams in the present study typically had two species present, one salmonid and one sculpin species.

In contrast to species richness, age class structure for species in the widely distributed salmonid and sculpin families were promising metrics. Multiple age classes of both salmonids and sculpins were infrequently encountered at sites with high percentages of fine grained surface sediments. These results support using salmonid and sculpin age classes as metrics for evaluating effects of sedimentation in small streams in Idaho. Factors that complicate interpretation of salmonid populations are reduced with sculpins. All salmonid species that occur in the study area are migratory to some extent (Meehan and Bjornn, 1991). Sculpins are apparently less motile than salmonids, are not stocked, and are seldom harvested. Apparently, sculpin age classes have not been used as a water quality metric anywhere in North America, although some investigators consider the number of sculpin species or sculpin abundances (Barbour *et al.*, 1999). Sculpin abundances could be useful metric in Idaho; similarly to age classes, sculpin abundances declined with increasing fine sediments (data not shown). In contrast, sculpin species richness would not be a useful metric in small streams in Idaho. In the present study, the number of sculpin species captured at minimally disturbed locations was usually one, with a maximum of two species. Other study results support using selected sculpin species as an indicator of excessive siltation (some species do tolerate fine grained substrates). In artificial stream experiments, when cobble substrates were embedded with fine substrates, Paiute sculpin (*Cottus beldingi*) densities were significantly decreased (Haro and Brusven, 1994). In field and artificial stream studies, Finger (1982) found that Paiute sculpin were restricted to riffle areas with loose rock with many interstitial spaces.

The different associations between measures of habitat structure and salmonid age classes (strong) and sculpin age classes (none), may indicate that the habitat measures included in Idaho's bioassessment process are more applicable to salmonids in streams than to the entire fish assemblage. Little or no relationships between non-salmonid fish assemblages and RBP habitat measures occurred in streams in Michigan, Minnesota, and North Dakota, U.S.A. (Lammert and Allan, 1999; Stauffer and Goldstein, 1997).

4.2.1. *Significance of Bankfull and Submerged Channel Substrate Measures*

The patterns between the macroinvertebrate metrics' responses and percentages of fine sediments measured as bankfull or instream sediments were unexpected. My expectation was that measuring only aquatic sediment particle sizes where they co-occurred with aquatic macroinvertebrates would result in stronger correlations than would sediment measurements that included dry, bank deposits. Most of the sites were sampled under the base flow conditions of mid-summer to early fall where the *majority* of the bankfull channel width is often out of the water. Yet for the 279 sites where both measures were calculated, all seven macroinvertebrate metrics were more strongly correlated with the bankfull percentages of fine sediments than with the instream percentage of fine sediments.

The percentage of fine grained sediments in the bankfull channel transect may better indicate upstream watershed disturbances than does the percentage of fine grained particles in the submerged portion of the channel. For natural streams, the recurrence interval for channel forming floods that fill the bankfull channel to overflowing averages about 1.5 yr (Leopold *et al.*, 1964). Thus, most of the bank and channel deposits measured in a bankfull channel transect originated higher in the watershed and are often the result of these flood events. If much of a watershed's area is disturbed with accelerated soil erosion due to loss of vegetative cover from causes such as fires, extensive logging, or poor agricultural practices, increased yields of fine grained sediments may be routed to stream channels. It follows that this increased delivery of fine grained particles will be reflected in a predominance of fine grained sediments in the bank deposits within the bankfull channel profile. These deposits may have lasting effects on the aquatic macroinvertebrate community, even though the percentage of fine sediments in the submerged channel becomes diluted in the months following the spring runoff.

5. Summary

Survey results of physical stream habitat characteristics, macroinvertebrate and fish community composition complement each other well, and provide valuable insights into the environmental condition of streams in Idaho. These results support the following conclusions:

1. Invertebrates responded to habitat degradation, increased fine sediment, and copper.
2. An additive multimetric index was responsive to these pollutants, but one component, the EPT index, was more responsive to these pollutants than was the index or any of its component metrics.
3. Invertebrate response relationships were similar in the arid, lowland ecoregions and in the montane ecoregions.
4. Salmonid fishes responded strongly to physical habitat features, but the more benthically oriented sculpins did not. Therefore, the habitat measures included in Idaho's stream assessment program are likely more relevant to salmonids in streams than the entire fish assemblage. Since Idaho's program is similar to many other state and federal programs in the United States, this is likely the case elsewhere.

5. Age classes of salmonids and sculpins were strongly associated with invertebrate responses. This agreement between the invertebrate and fish results support the use of either assemblage as general indicators of water quality.
6. High percentages of fine grained surface sediments interrupted salmonid and sculpin life cycles. Sculpins consistently avoided areas with abundant fine sediments in the stream channel or deposited on the banks – the more motile salmonids only responded to fine sediments in the stream channel.
7. The Wolman pebble count protocol is a biologically meaningful and efficient method to characterize surface sediment size distribution in streams. The bankfull measurements appear to reflect upstream watershed disturbances better than the instream sediment particle size distributions. The instream sediment size consistently affected invertebrate communities, and salmonid and sculpin populations. Particle size distributions measured over both the bankfull and instream channel widths provide complementary information.

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